X-ray Optics for the 2020's

Will Zhang
NASA Goddard Space Flight Center

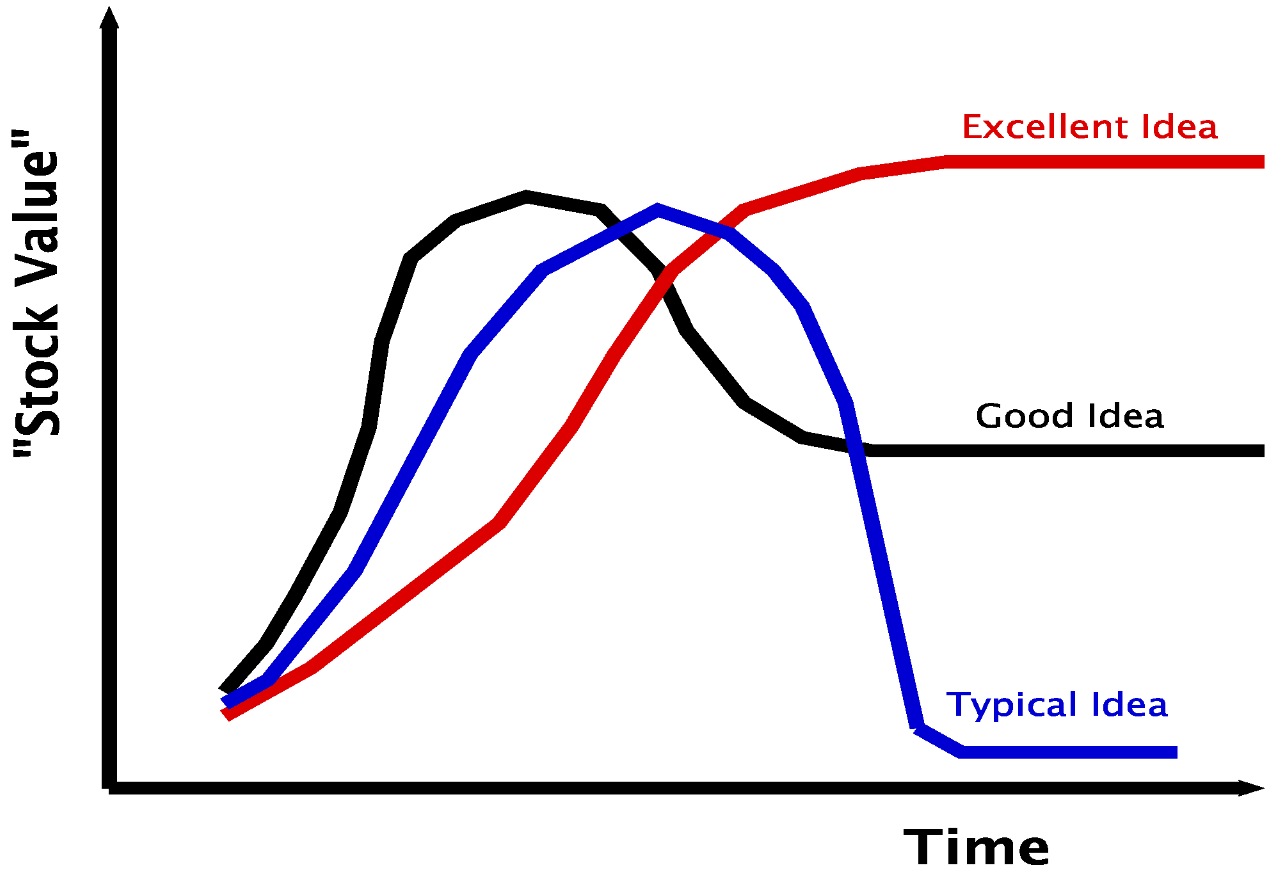
Criteria to Judge Optics

- Angular resolution
- Effective area
- Mass per unit effective area
- Energy band width
- Production cost
- Production schedule

Telescope for the 2020's

- Angular resolution must be ~1"-0.1" HPD
  - To image early Universe, complement JWST, etc.
- Effective Area must be > 1 m^2
  - To conduct high resolution spectroscopic studies
- Must launch on an existing rocket
- Must be amenable to multi-layering
- Must be manufactured in less than 5 years
- Must cost less than ~$500M

Evolution of Ideas



Two conundrums: (1) At any given time it is very difficult to know which curve you are on; (2) “Stock Value” does not necessarily equal to real value

Full Shell vs. Segment

- Full Shells
  - Einstein
  - ROSAT
  - Chandra
  - XMM
- Segments
  - ASCA
  - Suzaku

Segmented design is the way of the future!

Hierarchical Approach

- Size of the mirror segment
- Size of the module
- Other intermediary sizes
- Final mirror assembly

Rationalizing the Size of the Mirror Segment

- Arguments for large size for mirror segments
  - Large segments mean small number of mirror segments to make, handle, align, assemble
  - Large segments mean higher efficiency in achieving effective area
- Arguments for small size for mirror segments
  - Each mirror segment is much easier to make, handle, align, assemble
  - More copies are made of each mandrel, leading to lower mandrel cost
  - Smaller mirror segments are much more easily tested in the gravity environment

TotalCost = CostOfMaking-Handling-Aligning-Assmbling-OneMirror * TotalNumberOfMirrors

Rationalizing the Size of the Mirror Module

- Arguments for large module size
  - Similar to those for large mirror segment size
- Arguments for small module size
  - Similar to those for small mirror segment size

TotalCost = CostOfMaking-Handling-Aligning-Assmbling-OneModule * TotalNumberOfModules

Good Working Compromises on Mirror Segment and Module Sizes

- Mirror segment size: 200mm (axial) by 150mm (azimuth)
  - It can be measured with commercially available metrology equipment
  - It can be kinematically mounted with acceptable distortion
- Module size: 400mm (axial) by 150mm (azimuth) by 200mm (radial)
  - It can be kinematically supported with acceptable distortion
  - It can be tested with a horizontal x-ray beam

Mirror Segment Fabrication

- Slumping
  - Start with D263 or similar
  - Then move onto fused quartz/silica (ULE) for low CTE
- Cutting
  - Precision and introducing no stress
- Coating: preserving roughness and introducing no net stress
  - Single (or few) layer
  - Multilayer

Migration to Low or Zero CTE Material

- D263 Glass (CTE: 6.3 ppm/K) can probably make telescopes down to a few arcsec HPD. Beyond that, thermal distortion by temperature gradient may become an insurmountable obstacle
- Suitable materials for making higher resolution substrates
  - SiC for mandrels
  - Fused silica (or ULE) for substrates

Post-Slumping Figure Improvement

- Adjustment using actuators
  - Using piezo actuators (SAO, Leicester, etc)
- Adjustment using coating stress – Turning a bug into a feature
  - Pt, W, and other metal films can generate significant stress that can change low order figure of thin mirrors
  - If understood accurately enough, this type of stress can be used to improve low order figure of thin mirrors
- Polishing
  - Traditional method does not work because it applies too much shear stress that can break thin glass substrates
  - New figuring technologies
    - Ion-beam figuring (IBF)
    - Magneto-Rheological Figuring (MRF)
    - Reactive Atomic Plasma Technology (RAPT)

Two questions: (1) Is the figuring a converging process? (2) How to recover the micro-roughness after the figuring?

Characterization of Coating Quality

- Need to measure both overall reflectivity (throughput) and scattering (image quality)
  - Good reflectivity does no mean good image quality
- Definitive test
  - Use imaging forming mirror segments
  - Align and bond these segments
  - Measure image quality vs. energy in the band of interest

Mirror Segment Metrology

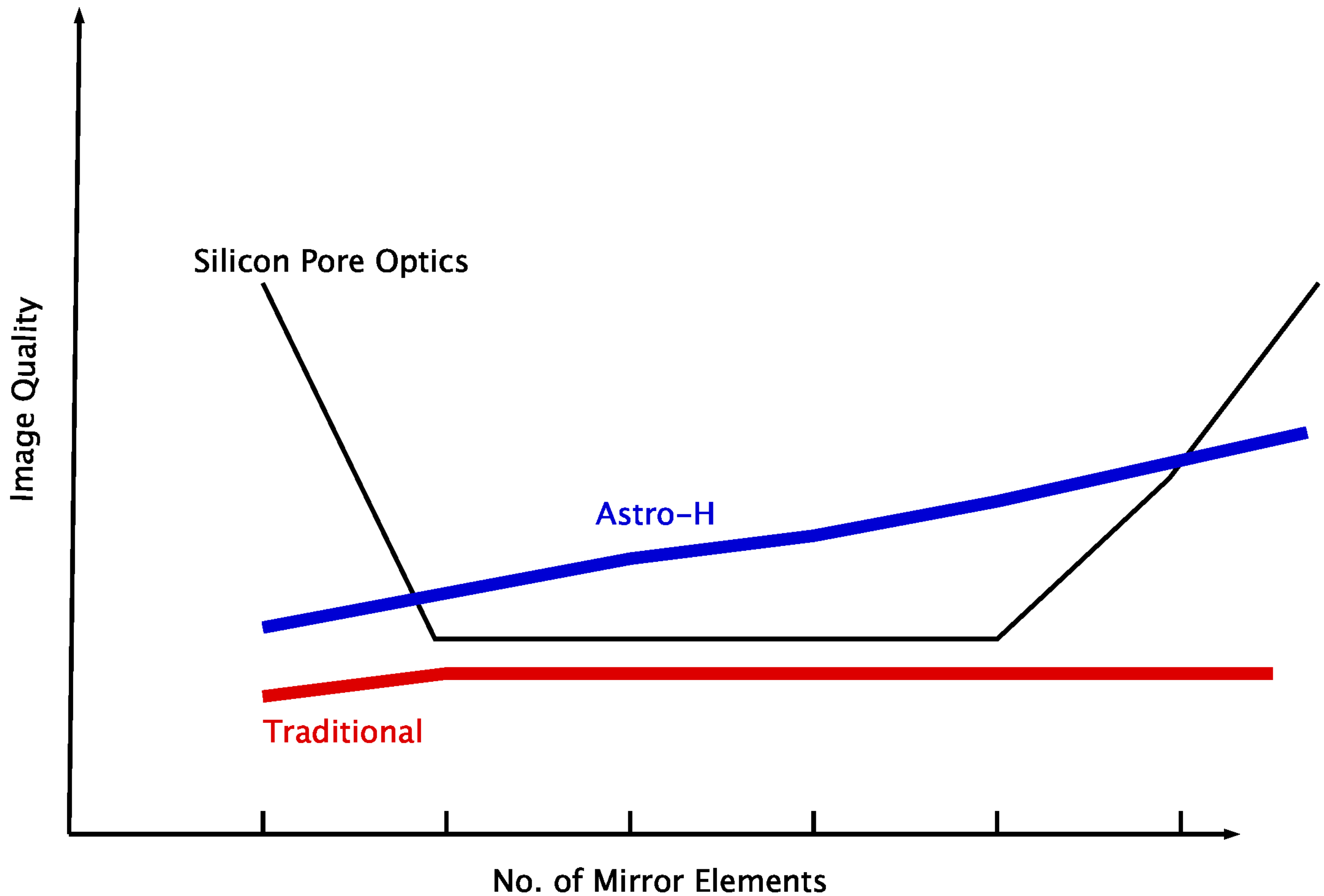
- Support or Fixturing
  - Repeatable and fully understood fixturing methods must be developed to enable measurement in the gravity environment
- One-Stop Complete Metrology
  - Grazing incidence and normal incidence measurements should be implemented together and simultaneously

Alignment and Integration

- This is a rapidly changing area of development
- Expected results in the next couple of years will significantly influence our thinking for the rest of this decade!

Stay tuned!

Image Quality vs. No. of Segments: Three Different Approaches



How to Conduct R&D before 2020

- Very limited resources
- Intelligently and rationally define and divide tasks
- Collaborate and compete
  - Each person (or institution) takes on a subset of the work
  - Each task is being done by more than one institution to ensure competition
  - All institutions collaborate to ensure common purpose and objective which is to make ready a technology for a mission in the 2020's